Polybenzimidazole membranes for zero gap alkaline electrolysis cells

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Membranes of m-PBI doped in KOH (aq), 15-35 wt%, show high ionic conductivity in the temperature range 20-80 °C. In electrolysis cells with nickel foam electrodes m-PBI membranes provide low internal resistance. With a 60 µm membrane thickness range 20-80 °C, KOH (aq), 15-35 wt%, show high ionic conductivity.

A promising ion-exchanging polymer is poly(2,2'-((m-phenylene)-5,5'-bibenzimidazole), m-PBI). When equilibrated in aqueous KOH solution the polymer deprotonates, and at >15 wt% KOH (aq) the potassium form predominates [1]. For membranes, this results in breaking of intermolecular hydrogen bonds, which decreases mechanical robustness and allows for significant swelling and electrolyte uptake. As a result, a ternary m-PBI-H2O-KOH system is formed which displays a high ionic conductivity.

**m-PBI**

One of the distinct disadvantages of alkaline electrolysis is the use of a thick porous diaphragm as an electrolyte containing separator. Commonly investigated alternatives are often anion exchange polymer membranes or ion-exchanging polymer membranes.

For membranes, this results in breaking of intermolecular hydrogen bonds, which decreases mechanical robustness and allows for significant swelling and electrolyte uptake. As a result, a ternary m-PBI-H2O-KOH system is formed which displays a high ionic conductivity.

**Cell polarization**

For zero gap electrolysis cell measurements, m-PBI membranes were equilibrated in aqueous KOH at a given concentration over night prior to cell assembly. Electrodes used were pressed (thickness ~ 210 µm) nickel foam, Figure 3. Current-voltage-curves are presented in Figure 4. Data were recorded by scanning the potential from 1.2 to 2.5 V at 2.5 mV/s. The cells were operated at 80 °C.

The cell house and external setup is displayed in Figure 5, on the right. Aprotic alkaline KOH solutions identified to the doping solution is circulated on both sides.

**Novel electrode concepts**

**Hydrogen evolution**

Increasing the active surface area of nickel catalyst is an efficient way to improve the hydrogen evolution activity. This is commonly done by using Raney catalysts, or by immobilizing nickel powder through the use of a binder, e.g. PTFE, or both [3].

We are using m-PBI polymer as a binder to make porous electrodes. The good alkaline stability and hydrophilic properties makes this an interesting binder for alkaline electrolysis in particular.

So far, we have prepared electrodes by first dissolving ~5 wt% m-PBI in alkaline ethanol (~5 wt% KOH in ethanol), and adding nickel powder to form a viscous mixture. The mixture was applied by a dip-coating procedure, in which nickel foam pieces was briefly submerged and otherwise left to dry in air.

A polarization curve for such an electrode is presented in Figure 6, compared to a non-coated nickel foam electrode.

**Oxygen evolution**

Increasing the active surface area of nickel does not seem to have the same effect on the OER compared the HER, and stability issues are more severe for OER. However, recent research have shown that Fe-doped nickel isodes a very active OER catalyst [6].

Electrodes can be made in various ways, here, Figure 7, an electrode prepared by a hydro thermal process using urea, and nickel and iron nitrates is presented. This demonstrates a huge potential for overall cell improvements.

**References**


**Figure 1.** Deprotonization of m-PBI happens at high pH and the precipita-
tion form of m-PBI is predominated in KOH (aq) solutions of more than 15 wt% KOH.

**Figure 2.** Conductivity of the m-PBI membranes measured in a lab-
ber PTFE cell with 2 expanded nickel mesh electrodes. Temperature was controlled by placing the assembly in a heating cabinet. Electrochemical Impedance spectra were recorded, and the resistance taken as $R_{in} = 0$. Membrane conductivity, $\sigma$, was found by subtracting a blank sample measurement.

$\sigma = 1 / [V_{oc} / \Delta V]$

While the uncertainty is larger in the 15-25 wt% KOH concentration range where the conductivity peaks, there is a trend that suggests a conductivity peak near 20-25 wt%, which is lower than for bulk solution. At 25 wt%, we measure 146 mS/cm at room temperature and 255 mS/cm at 80 °C.

Previous measurements have shown a peak conductivity of 130 mS/cm for 20 wt% KOH at room temperature.

**Figure 3.** Measured conductivity, $\sigma$, of m-PBI and bulk solution on different concentrations of aqueous KOH at varying temperatures.

**Figure 4.** Current-voltage-curves are presented in Figure 4. Data were recorded by scanning the potential from 1.2 to 2.5 V at 2.5 mV/s. The cells were operated at 80 °C.

The cell house and external setup is displayed in Figure 5, on the right. Aprotic alkaline KOH solutions identified to the doping solution is circulated on both sides.

**Figure 5.** Cell polarization at 80 °C with m-PBI membranes of different KOH (aq) concentrations. Thicknesses of prepared nickel foam. Membrane thickness in the range 50-60 µm. Thickness of ZrW is about 900 µm.